

Conformable array for mapping corrosion profiles

By Alfred E. Crouch¹ and Patrick C. Porter²

¹Southwest Research Institute, San Antonio, Texas

²Clock Spring Company, Houston, Texas

**14th Annual Pipeline Pigging, Integrity Assessment
& Repair Conference**

Omni Houston Westside
Houston, Texas

January 23-24, 2002

Conformable array for mapping corrosion profiles

In a new project sponsored by the Department of Energy's National Energy Technology Laboratory, feasibility is being determined for a fast, inexpensive method to map corrosion on the outside of pipelines. If successful, the work will lead to a system that is easily deployed in the field environment by pipeline maintenance personnel, producing a contour map of corrosion depth. The collected data will support B31G, RSTRENG and other assessment algorithms, which rely on 3-dimensional corrosion sizing. The array will contain multiple eddy current sensors, scanned electronically to collect lift-off data that represent local wall-loss measurements. The work is being performed at Southwest Research Institute with the cooperation and co-funding of Clock Spring Company.

Background

In-line inspection by itself does not provide clear-cut answers to all the questions about corrosion severity in a pipeline. In cases where the corrosion is classified as very light (< 15%), the pigging results are generally taken at face value and no field investigation is deemed necessary. In cases where the corrosion may be significant enough to require repair, replacement or lowering of MAOP (Maximum Allowable Operating Pressure), follow-up is usually made in the field using investigative digs and local measurement of remaining wall thickness. Once the dimensions of the corrosion patch are determined, an assessment algorithm such as B31G or RSTRENG can be applied to determine the remaining strength of the pipe. For B31G, the length of the corrosion and the maximum pit depth are the only data required in addition to the nominal pipe dimensions. For RSTRENG, multiple depths are used, following a "river-bottom" path through the corroded patch.

Regardless of which assessment method is used, the input data are usually provided by local measurements on the outside of the pipe, in the pipeline excavation (bell hole). The simplest case is that of a single isolated pit. A scale can be used to measure the length of the corroded area. A dial extension gage (pit gage) can be placed over the pit (assuming the base will span the pit) and the maximum depth read and recorded. Slightly

more complicated is the case of several overlapping pits or a small-corroded patch. In this case, the length can still be read from a scale, but the pit gage base may not span across the corroded patch to rest on the pipe reference surface, so the depth measurement will be in error. In this case, an attachment such as a bridging bar (Figure 1) is often used. The bar is long enough to span across the corroded area and provide a pipe surface reference from which a depth gage can measure the corrosion depth.

When the corrosion is extensive, it is not always apparent from visual inspection which spot is the deepest, or which path through the patch is the correct river-bottom track. In those cases, an auxiliary grid is often employed to help construct a contour map of the corrosion. A rectangular pattern of measurement points on, for example, 1-inch spacing is drawn or painted onto the pipe surface including the corroded area. A bridging bar or a hand-held ultrasonic probe is used to make measurements at each grid point. From this array of measurements, either manual or computer-aided processing is used to construct a contour map.

All of these manual methods are laborious and very time-consuming. It can take the better part of a day to make all the grid measurements on an extensive corrosion patch. Furthermore, the environment of the pipeline bell hole is not always user friendly. Rain, cold and other inconveniences can take a toll on operator attention and consequently, accuracy of measurement. This is particularly true if the corrosion patch is on the bottom of the pipe. So, it has been apparent that a better way was needed.

One early solution to the manual prove-up problem was developed by Edison Welding Institute. They developed a laser range-finding system that will automatically scan a corroded area and collect very accurate data of the corrosion depth. Marketed by RTD of the Netherlands under the name LPIT, the system is shown in Figure 2. Although the LPIT provides accurate depth measurements on a very high-resolution grid, there are some shortcomings in its application. First, the pipe surface needs to be quite clean. Any dirt or residual pipe coating will cause the measurements to fall short of the true depth. Further, the hardware is bulky, relatively expensive and likely subject to damage from rough handling.

Project Objectives

The goal of this project is to determine the feasibility of measuring external pipeline corrosion with an eddy current array in a flexible form that can be wrapped around the pipe and scanned electronically without extensive operator involvement. SwRI had an earlier project for the New York Gas Group (NYGAS) in which a single eddy current coil was optimized for measurement of the depth of graphitic corrosion in cast iron pipe. If multiple coils can be provided in a wrap-around sheet, then conceivably an entire corrosion patch can be measured in a single set-up. Scanning and multiplexing circuitry can be used which will activate one coil at a time and record the measurement data before moving to the next coil. In a reasonably short time, then, a significant area can be covered.

The proposed concept is illustrated in Figure 3. The eddy current response is only due to the distance between the probe and the nearest electrically conductive surface. It is, therefore, insensitive to any dirt or residual coating material on the corroded surface as long as that material does not cause the array to lift above the nominal pipe surface

profile. Note that the flexible array shown in the figure can be deployed equally well on the top, bottom or sides of the pipe.

The goal is to have the electronics for the array simple enough that they can be packaged in an add-on box to a notebook computer and be battery powered for convenient use in the field.

Measurement Accuracy

For the purpose of this first prototype device, we assume that B31G will be the code used to provide the assessment. More sophisticated defect assessment will be considered in the next phase of development.

Length

The accuracy of defect length measurement is a function of defect depth. If the defect is shallow (<0.100 inch [2.5 mm]), then 0.5-inch [13-mm] accuracy is assumed to be good enough, but as the defect gets deeper, the length becomes more important. For defects that are >0.100 inch [2.5 mm] deep, the length measurement should be $+0.125$ inch [3 mm] – 0.0.

Circumferential Extent

The circumferential extent is less important than the length and is only required to determine defect interaction. Interaction occurs when there is a cluster of pits separated by a small distance. B31G does not address interaction. CSA Z662 states, "Corroded areas in close proximity shall be considered to interact if the distance between them is less than the longitudinal length of the smallest area. The longitudinal length in all cases shall be measured along the longitudinal axis of the pipe."

When assessing a single isolated defect, the circumferential extent is not used; therefore, the accuracy is not important. However, to determine interaction will require the same level of accuracy as the length measurement.

Depth

The accuracy of the depth measurement is a function of defect depth. Shallow defects (<0.100 inch [2.5 mm]) should be measured more accurately than deep defects. Defects <0.100 inch [2.5 mm] should be measured to $+0.005$ inch [0.13 mm] – 0.0. Deeper defects can be measured to $+0.015$ inch [0.4 mm] – 0.0.

Defect Size

The diameter of the smallest isolated pit that will be measured will be greater than $3t$ (3 times wall thickness). This is derived from current inspection tool performance and from B31G. Even very deep defects ($0.8t$) can have a diameter of 1 inch [25 mm] or more before requiring repair. In patch corrosion, the individual segments within the patch only become important when using advanced assessment techniques. For the purpose of this prototype device the minimum diameter to be measured will be 0.75 inch [19 mm].

Eddy Current Lift-Off Measurement

If a coil of wire carrying an alternating current is placed near an electrically conductive material, the magnetic field from the coil will cause currents to flow in the conductive material in a reverse direction to those in the coil. The magnitude and phase of these secondary currents are influenced by the geometry of the arrangement and the conductivity and magnetic permeability of the part. The spacing between the coil and the conductive material is part of the geometry of the arrangement. With suitable instrumentation and signal processing, the coil-to-workpiece spacing can be measured. This “lift-off” effect is a common noise source that one seeks to eliminate when an inspection targets cracks or material properties. However, in the case of near-surface corrosion, the lift-off effect carries information about corrosion depth, so the lift-off signal component is the one that is retrieved.

Figures 4 through 7 show the change in coil impedance as an eddy current coil is placed at various lift-offs above a steel plate. Both the resistive component (R) and the reactive component (X) are shown since the electronics will have the option of using either component as a measure of lift-off. Note that the four charts cover four different frequencies from 50 kHz to 1 MHz. Figure 8 is a drawing of the coil that is being used. It is a flexible coil in the form of an octagonal spiral. For this particular coil, note that the resistive component of coil impedance is most sensitive to lift-off at 1 MHz and for frequencies below 100 kHz, the resistive component contains almost no information. At those frequencies, the reactive component responds better to lift-off.

Pit Depth Measurement

The same coil was used to make impedance measurements at the centers of 31 machined pits in a 0.5-inch [13-mm] thick steel plate that is 15 inches x 18 inches [381 mm x 457 mm]. The pits are in rows of constant diameter and increasing depth as shown in Figure 9. The depths and diameters are shown in Table 1.

For an initial test of the flexible coil, it was hand-held at the center of each of the machined pits and computer control was used to sequentially set the Hewlett Packard 4194A Impedance Analyzer to four different frequencies: 50 kHz, 100 kHz, 525 kHz and 1 MHz. At each of these frequencies, the resistive and reactive impedance components were measured and recorded in computer memory. At the end of the test, the files were transferred into a spreadsheet for analysis and plotting.

It was not expected that the coil lift-off response would accurately measure pits that are smaller than the diameter of the coil or even close to the coil diameter. When plotting the coil response, separate charts were used for pit diameters 0.5 inch [13 mm] and less and for pit diameters 0.625 inch [16 mm] and greater. Figures 10 and 11 show the smaller pits at 50 kHz and 1 MHz, respectively. Figures 12 and 13 show the larger pits for those same frequencies. The 50 kHz data are the reactive component values and the 1 MHz data are the resistive component values. Those components were selected based on the behavior at those frequencies during the lift-off test.

Note in Figures 10 and 11 that there are three data points that form a curve parallel to the rest of the data. These points are from the 0.25-inch [6.4-mm] diameter pits. It is encouraging that the 0.375 inch [9.5 mm] pit data fall onto the same curve as the 0.50

inch [13 mm], and indeed, as a comparison of Figures 10 with 12 and 11 with 13 reveal, all the data from 0.375-inch pits and larger, fall together. This suggests that the pit diameter effect is not significant for pits whose diameters are larger than the coil diameter.

Array Design

At the time this paper is being written, the array design has not been done. Some design concepts, however, have been discussed. One of the key questions to be addressed is what the density (spacing) of the array needs to be to adequately map corroded areas. In the simple case that is suggested by Figure 3, the array will be placed onto one position on the corrosion patch and all data will be collected at that position. This means that the individual coils must be close enough that they do not miss the deepest corrosion. Although the validation testing is yet to be done, the assumption is that this requirement will result in coils no more than 0.25 inch [6.4 mm] apart. If the array must cover a corrosion patch that is 12 inches [300 mm] square, that will require over 2000 individual coils. Using modern printed circuit techniques, that is not prohibitive. Furthermore, array-addressing methods are available to handle data collection from that number of coils.

However, it may not be necessary to use this “brute force” approach. We are considering a movable array that can collect data quickly in one position, be shifted slightly and collect data again. After several coordinated moves, data will be sufficient to produce a contour map with significantly greater resolution than the native coil spacing would suggest. For example, an array with small coils spaced 0.5 inch [13 mm] apart could produce an image with a resolution better than 0.25 inch [6.5 mm] if the data were collected at several different positions with respect to the corrosion.

Application

The conformable array has three unique applications: (1) defect profiling to help inspection vendors calibrate inspection runs, (2) record keeping to meet regulatory requirements and to qualify future inspections and (3) defect assessment in a timely fashion.

Before rehabilitation or defect assessment can take place, the pipeline must be inspected to determine its condition. In-Line-Inspection (ILI) tools are the most common method of carrying out the inspection task. An inspection tool is a device that is loaded into the pipeline and propelled through the pipe by the flowing product. As it travels, it measures and records information on the condition of the steel in the wall of the pipe. When the tool is removed from the pipeline, the data are reviewed and potential problems identified. These problem areas can be subjected to an on-site investigation to determine if corrective action is required.

The most common technology used for the in-line inspection task is Magnetic Flux Leakage. This is a complex but robust technology. Defect profiles are not directly measured but rather must be inferred from a detailed analysis of the magnetic data. The magnetic data are not only influenced by the defect in the pipe wall but also by the material properties of the steel and the operating conditions of the tool. When measurement errors occur, they can be corrected or minimized with additional calibration

information. For this calibration information to be useful, it must accurately reflect the physical properties of the defect. The conformable array will be able to provide calibration information in a convenient digital format to the inspection vendor such that an inspection can be graded more accurately. This alone can save large amounts of money for the operator.

In addition to providing calibration information, the conformable array will provide a convenient method of record keeping that will satisfy the regulators and provide a rich source of defect information that can be used to assess and qualify subsequent inspections. If a defect is measured and repaired with a technology that does not affect the magnetic properties of the pipe, then that measurement information can be used on subsequent inspections to help calibrate the inspection. These data can also be used to ensure that the inspection company has complied with detection and sizing specifications outlined in the contract. It can qualify a tool run. This qualification aspect will become more important as inspection is imposed on the industry.

The main purpose of the array, however, is to measure defects for repair assessment. In the coming months, U.S. pipeline operators will be completing plans to comply with the U.S. Department of Transportation's Research and Special Programs Administration (RSPA) mandatory Integrity Management Program, also known as the IMP rule. These new regulations will spur a significant increase in pipeline maintenance activities. Mergers, acquisitions and consolidation of energy resources involving the transfer of assets will also impose tighter schedules on maintenance activities. In this process, operators will have to assess defects detected by inspection tools, select repair alternatives and develop maintenance procedures to ensure an effective and timely response.

The goal of the conformable array is to meet the need for fast, accurate defect assessments in the field so that repair decisions can be made on site and repairs completed while the defect is initially exposed. While this system's accuracy is not likely to compete with the accuracy of a laser scanner, it should nevertheless be capable of providing the information needed to assess repair requirements and alternatives.

Conclusions

Tighter scheduling imposed on operators and the increasing need to qualify pipe inspections demand new technology. The conformable array is planned to be one of the tools that can gather defect information to assess defects, calibrate inspection equipment and qualify inspection results.

Acknowledgements

The authors would like to acknowledge the technical assistance of Mr. Gary L. Burkhardt and Mr. David Jones in this project. They also acknowledge the support and review of this work by Mr. John Rogers of the DOE's National Energy Technology Laboratory, which is providing primary funding for the work through their Natural Gas Infrastructure Program, Contract No. DE-FC26-01NT41153.

Bibliography

Libby, Hugo L. "Introduction to Electromagnetic Test Methods", Krieger Publishing Company, 1979.

McMaster, Robert C. "Nondestructive Testing Handbook", Volume II, Society for Nondestructive Testing, The Ronald Press, 1963.

Baron, Leemans and Dolbey, "An Eddy Current Technique to Estimate Dimensions of Crevice Corrosion Pits," ASTM Special Technical Publication 908, ASTM Publication Code No. 04-908000-27, 22-24 May 1984.

Bugar and Moulder, "Use of Eddy Current Sensors for Controlling Probe Lift-Off Actively During Scans," Review of Progress in Quantitative NDE, V. 13, Plenum Press, 1994.



Figure 1. Bridging bar for field measurement of external corrosion



Figure 2. RTD's laser gaging tool (LPIT)*

*Photograph from RTD Quality Services web site.

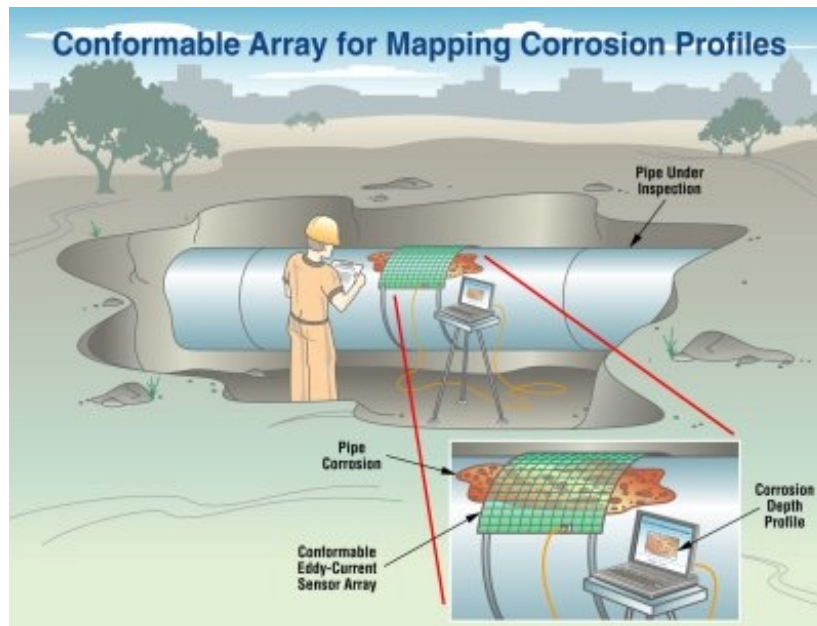


Figure 3. Concept of conformable array

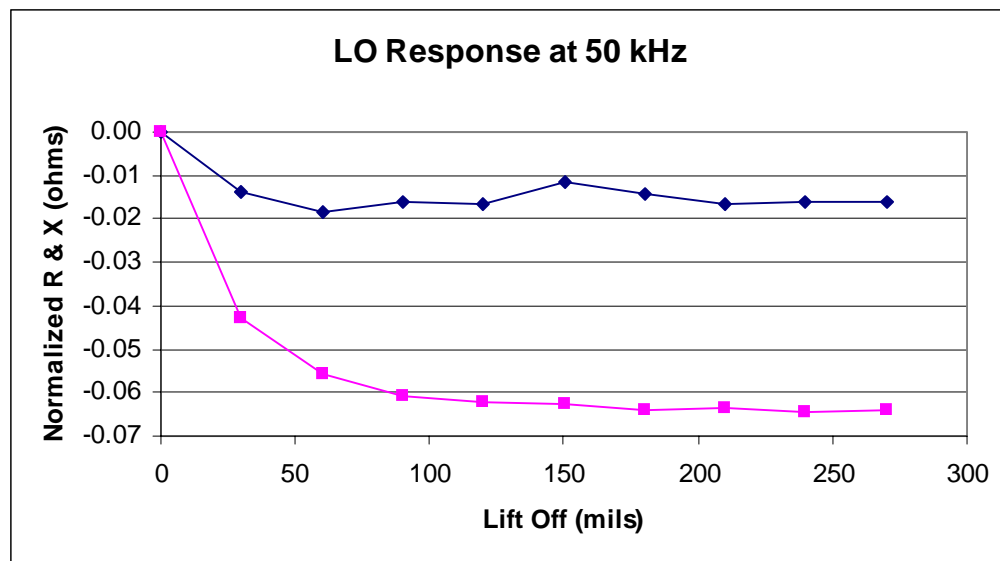


Figure 4. Resistive (diamonds) and reactive (squares) components of coil impedance at 50 kHz

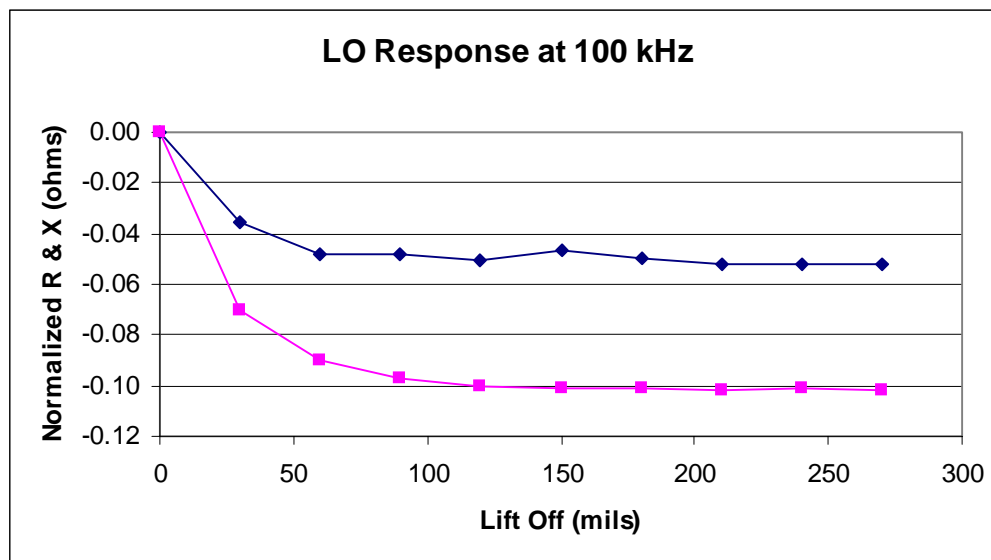


Figure 5. Resistive (diamonds) and reactive (squares) components of coil impedance at 100 kHz

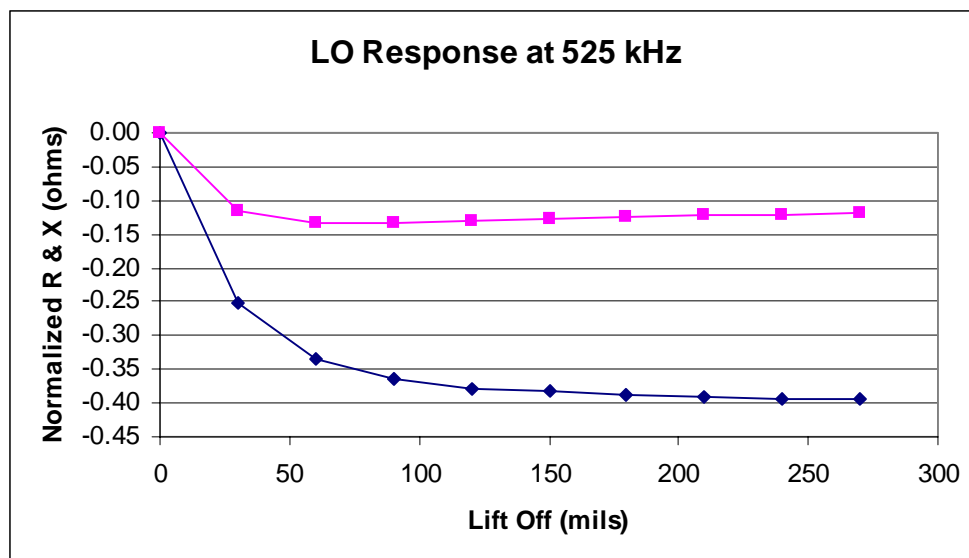


Figure 6. Resistive (diamonds) and reactive (squares) of coil impedance at 525 kHz

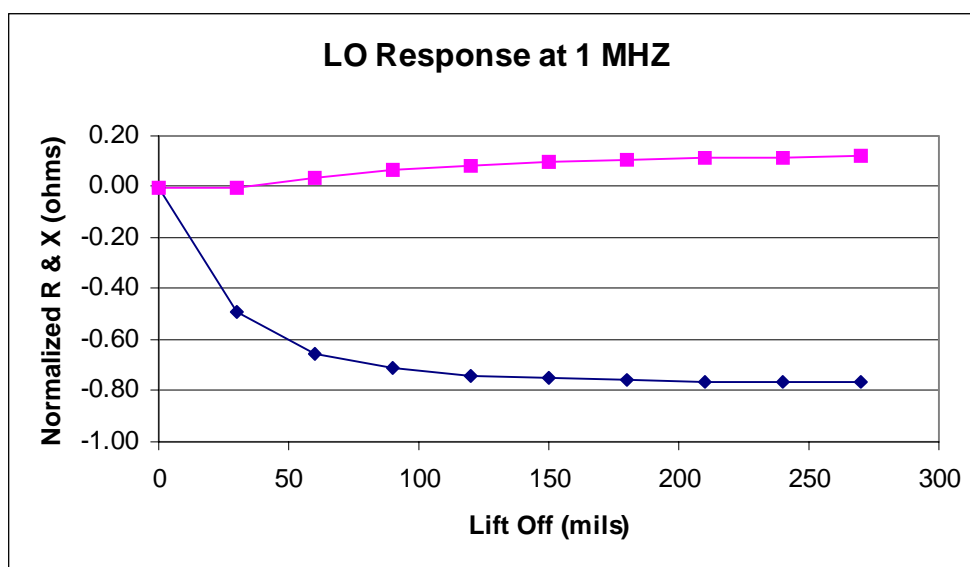


Figure 7. Resistive (diamonds) and reactive (squares) components of coil impedance at 1 MHz

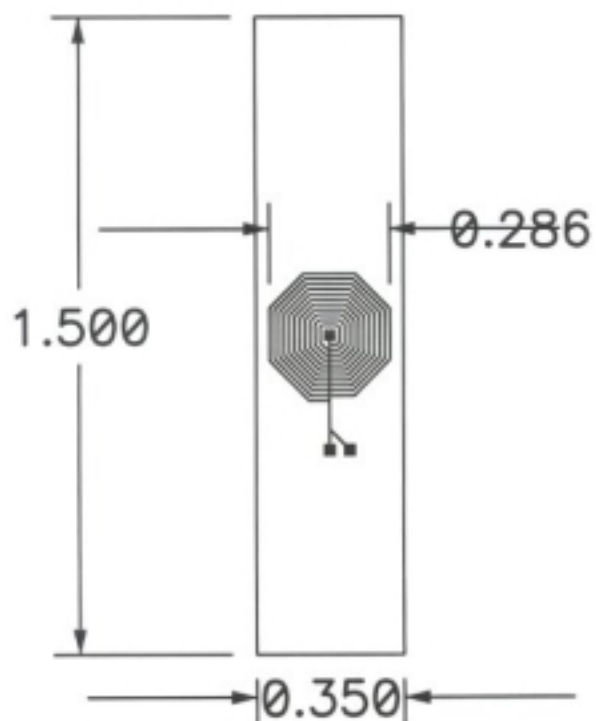


Figure 8. Flexible coil layout

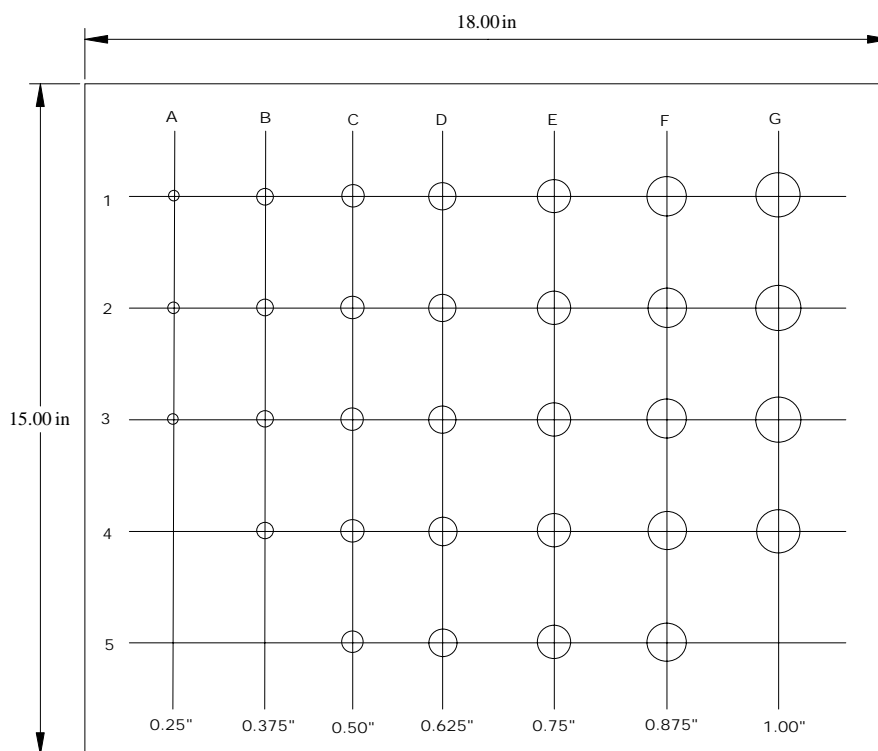


Figure 9. Layout of steel test plate

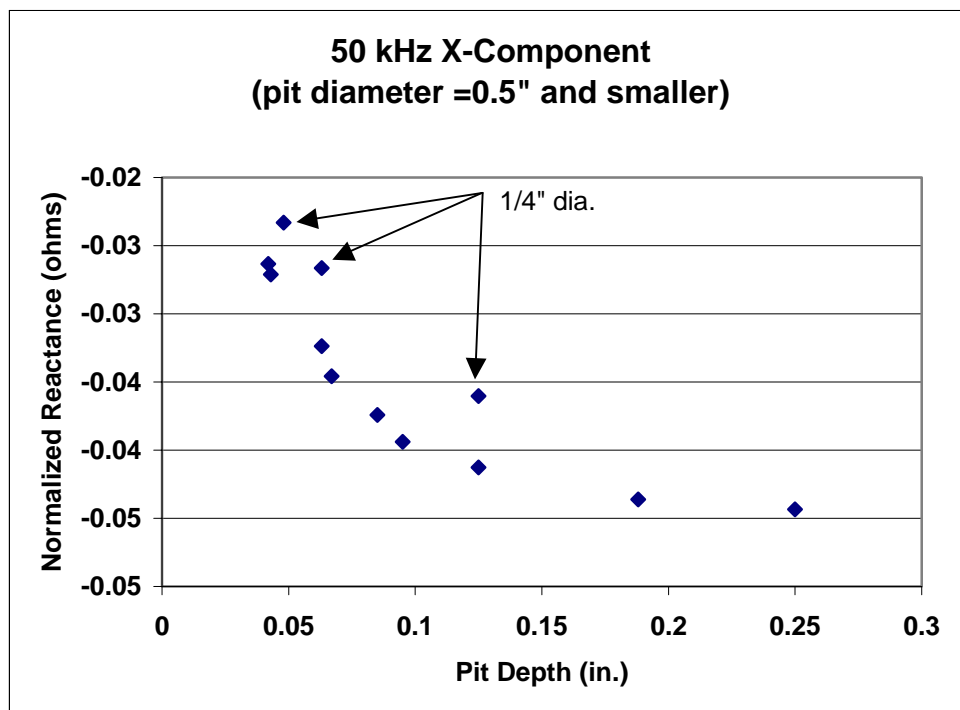


Figure 10. Pit depth response for small pits at 50 kHz

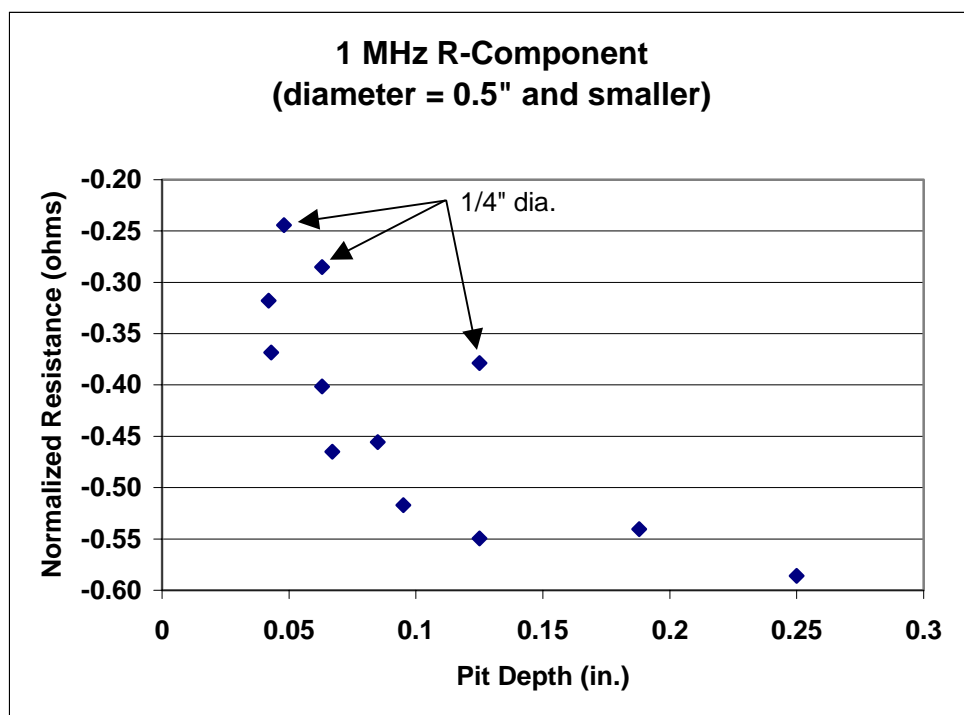


Figure 11. Pit depth response for small pits at 1 MHz

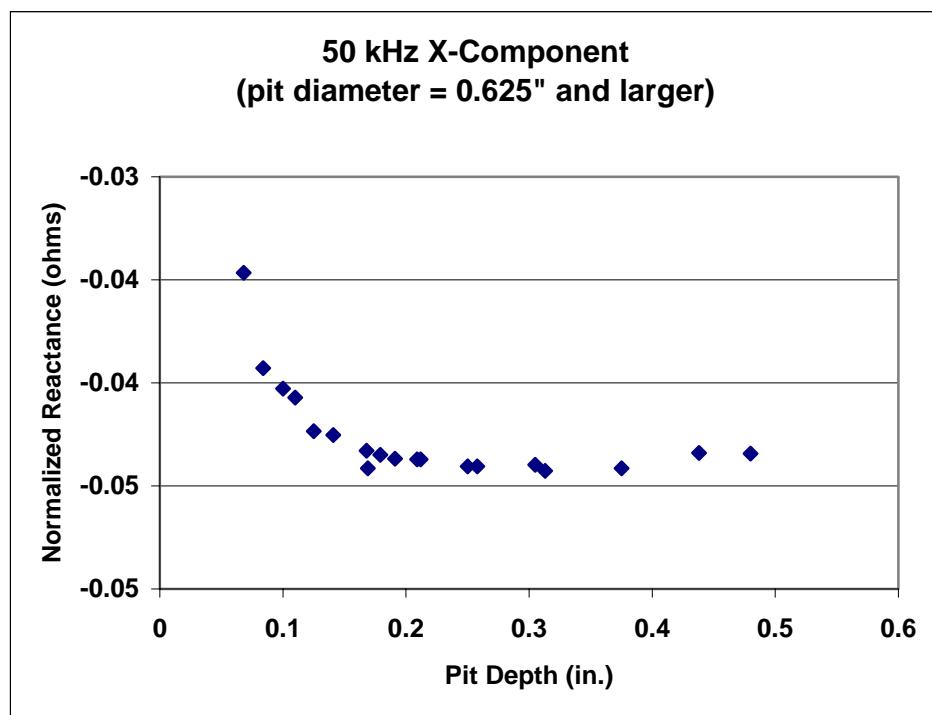


Figure 12. Pit depth response for large pits at 50 kHz

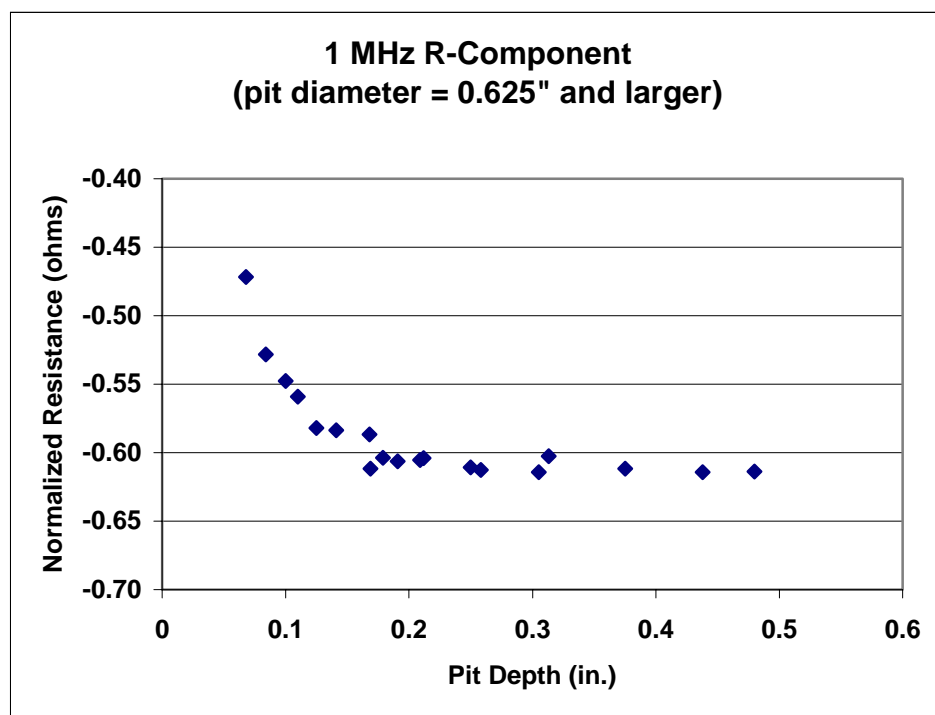


Figure 13. Pit depth response for large pits at 1 MHz.

Table 1. Pit sizes in steel test plate

Column	No. of pits	Diameter (in.)	Min. Depth (in.)	Max. Depth (in.)
A	3	0.250	0.048	0.125
B	4	0.375	0.042	0.188
C	5	0.500	0.043	0.250
D	5	0.625	0.068	0.313
E	5	0.750	0.100	0.375
F	5	0.875	0.141	0.438
G	4	1.000	0.191	0.480